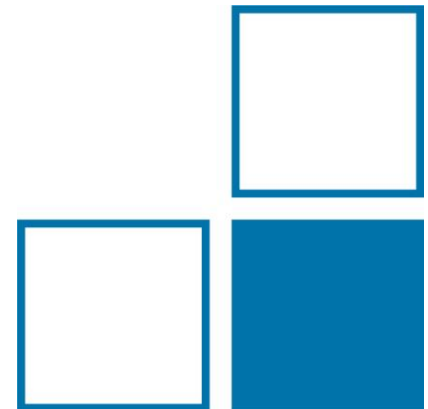
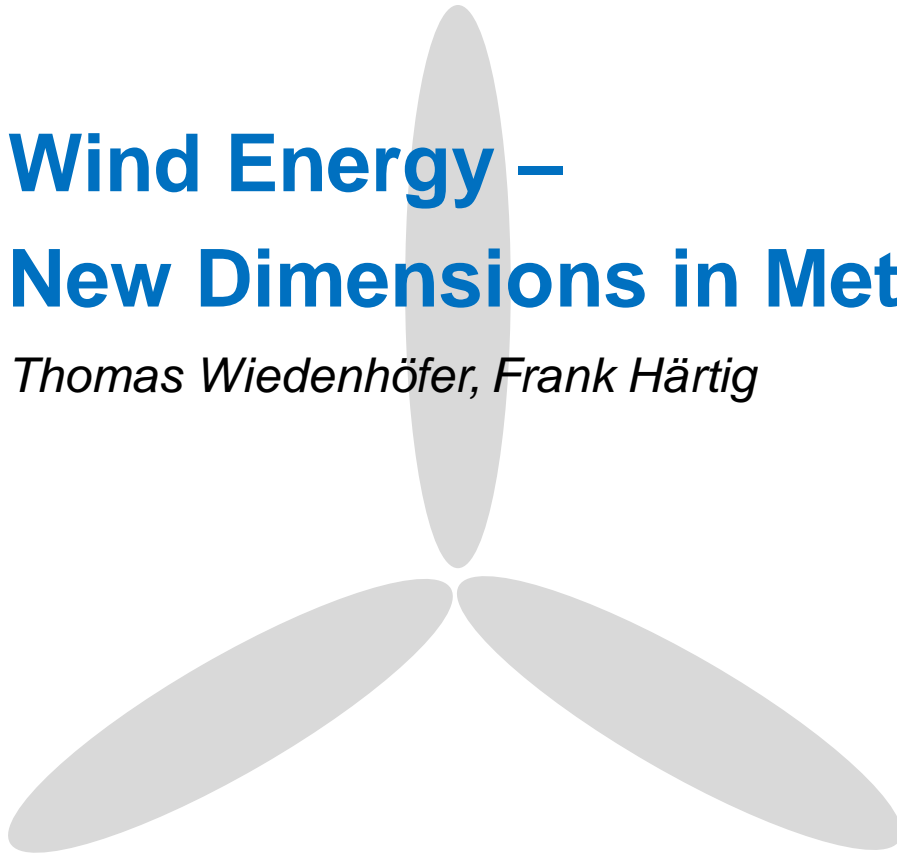


# Wind Energy – New Dimensions in Metrology

*Thomas Wiedenhöfer, Frank Härtig*



sailing vessels in the  
ancient Egypt

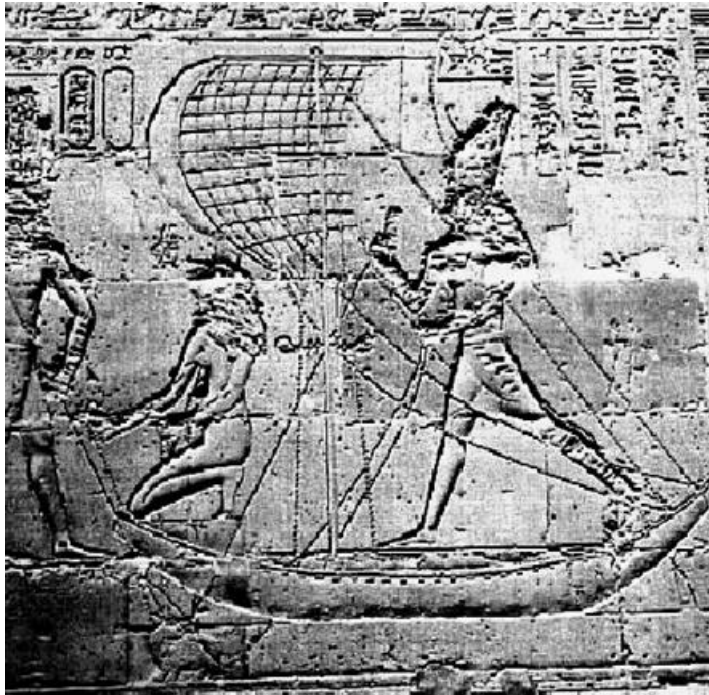
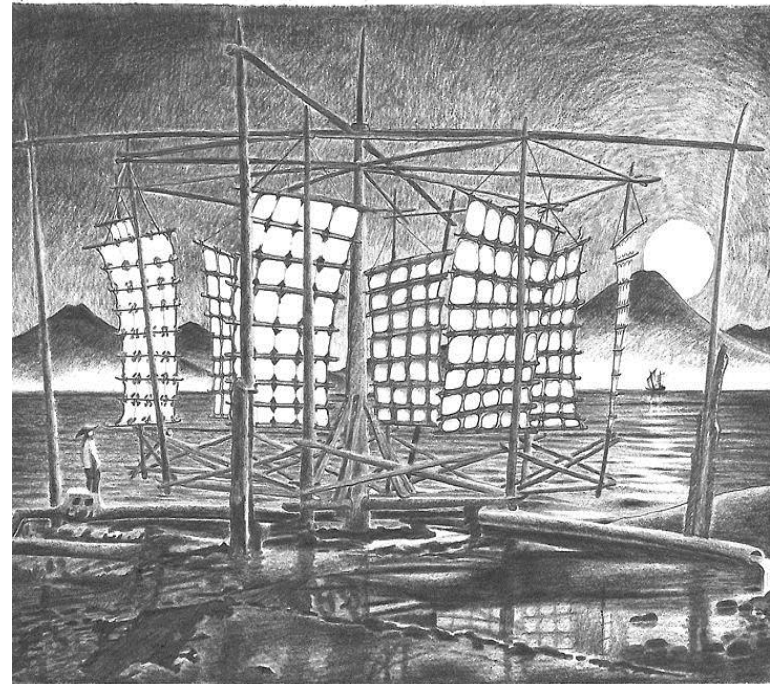


photo: Elvira Kronlob

windmills in China



source: Carl von Canstein

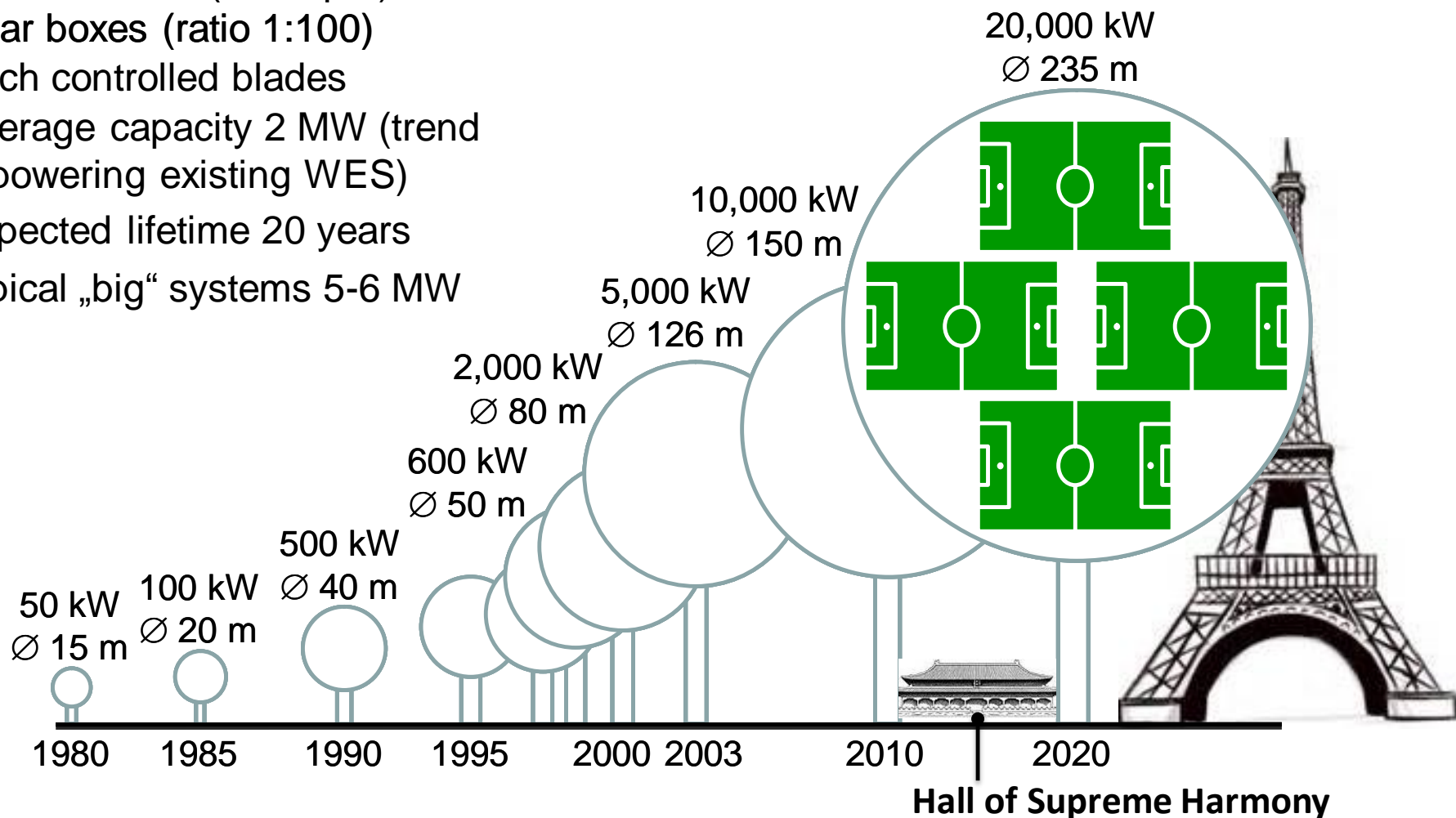
- Core environmental and sustainable objectives
  - reduction of greenhouse gases
  - avoidance of pollution / dangerous waste (coal / nuclear plants)
- Technical and economical objectives
  - competitiveness with conventional energy supply
  - reliability, safety, reasonable maintenance (lifetime 20 years)
- Political objectives
  - secure energy supply (at all weather conditions)
  - development of structured grids
  - reduction of subsidies and infrastructure costs

Germany:      renewable energy sources act  
2020 35% renewable energy; ( today 25%)

# Development and forecast of WES sizes

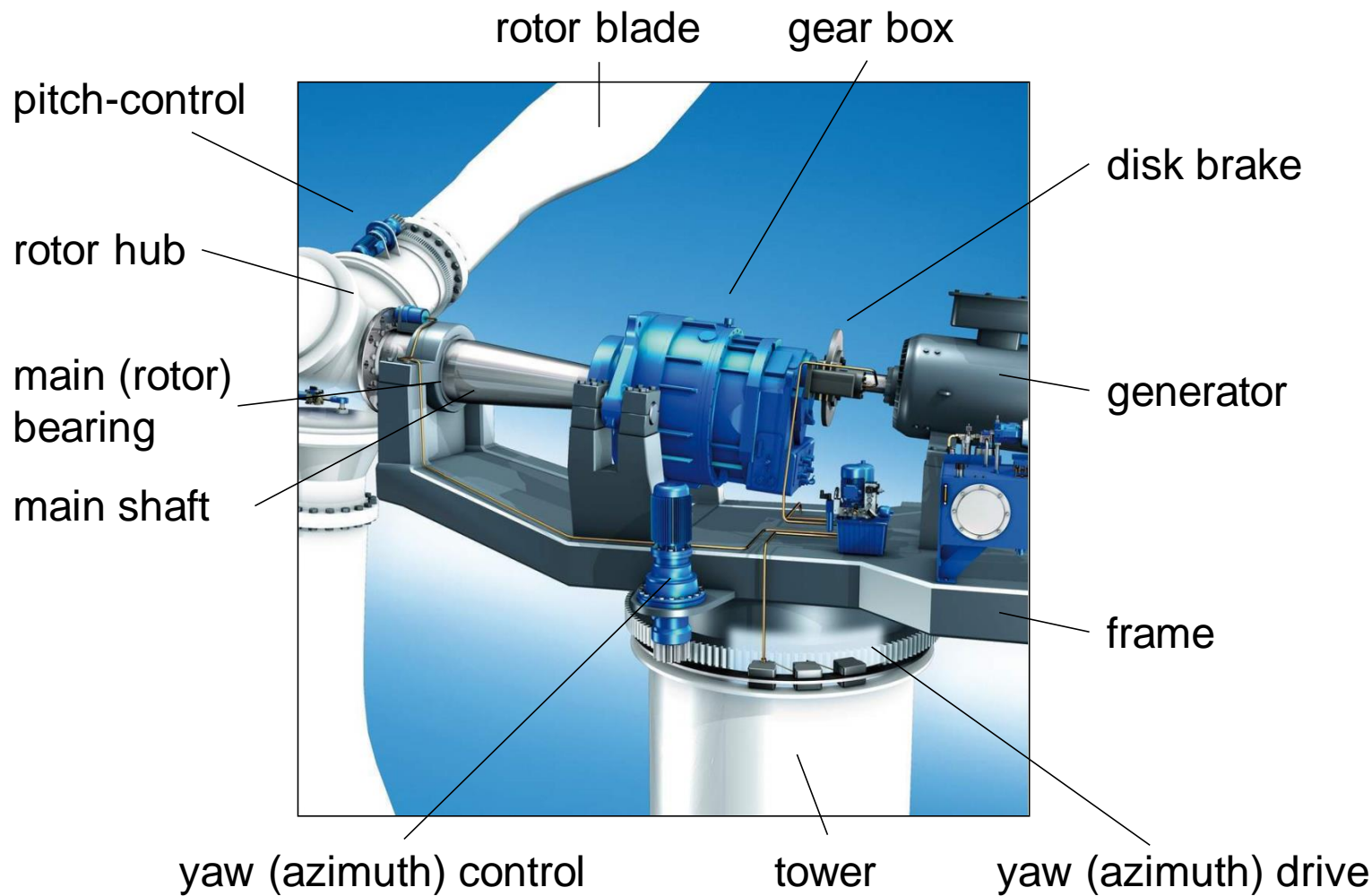
In less than 30 years, the yield from wind turbines has increased more than **500** times

- 3 blade rotors (6-15 rpm)
- gear boxes (ratio 1:100)
- pitch controlled blades
- average capacity 2 MW (trend repowering existing WES)
- expected lifetime 20 years
- typical „big“ systems 5-6 MW



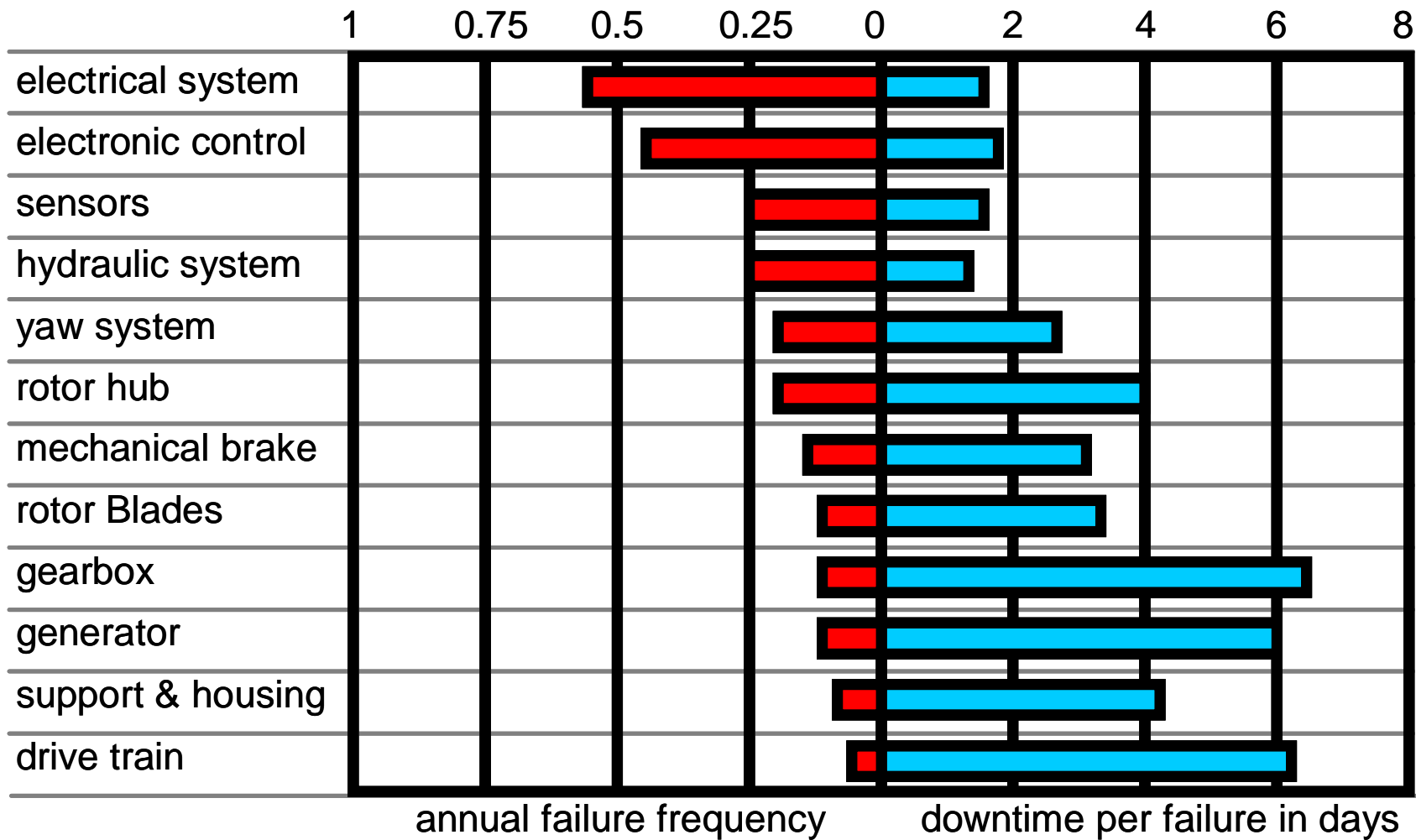


# Components of the WES drive train



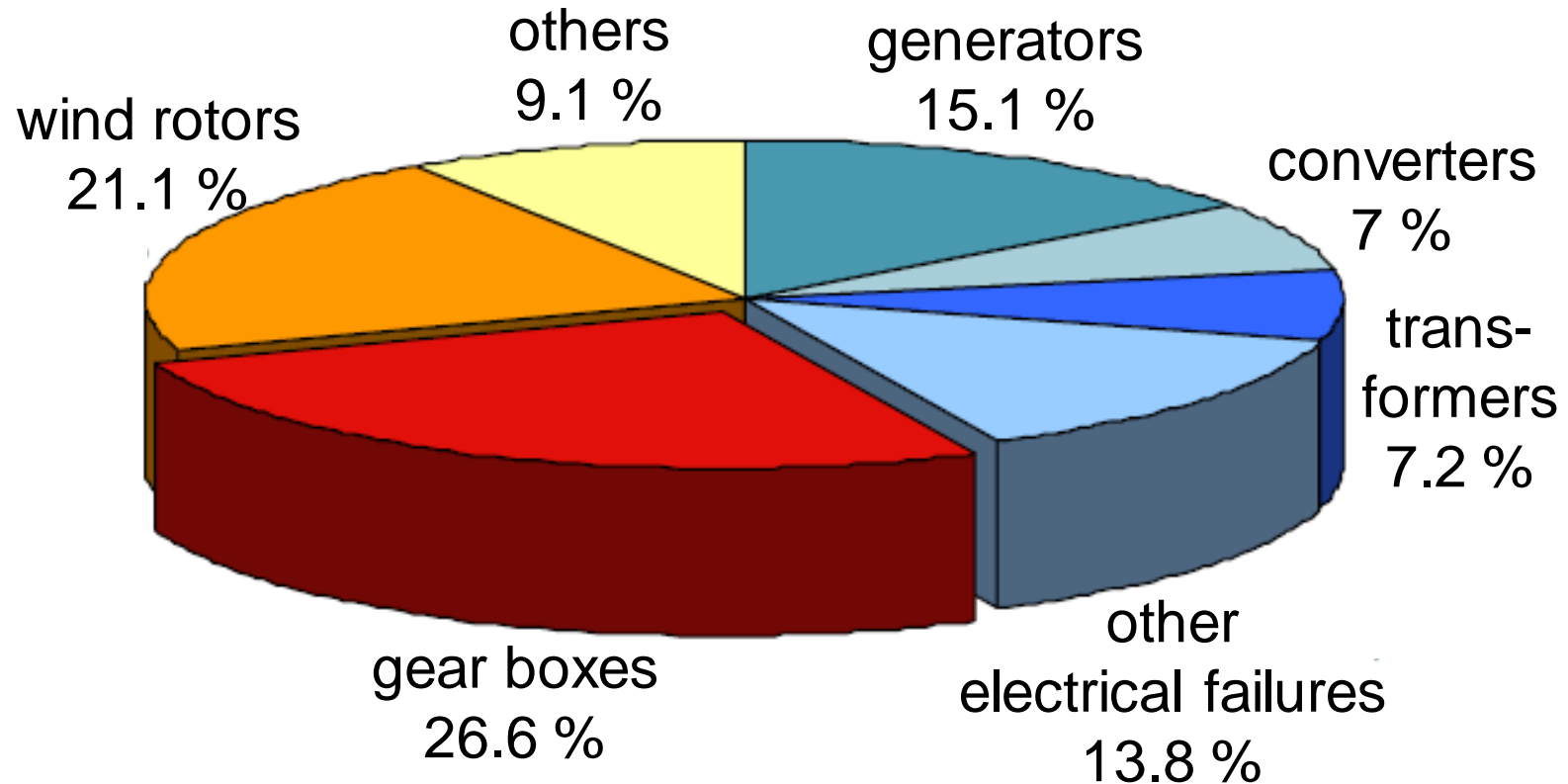
source: Bosch-Rexroth

# Failure frequencies and impacts



source: Fraunhofer IWES, Kassel

# Cost distribution caused by WES failures '09



source: Sensen, Gothaer Allgemeine Versicherung AG

## Biggest systems in dimensional metrology:

PTB / NPL / NMIJ, ... : measuring volume  $< 1\text{m}^3$

problem: no standards  $> 1\text{m}^3$  available worldwide

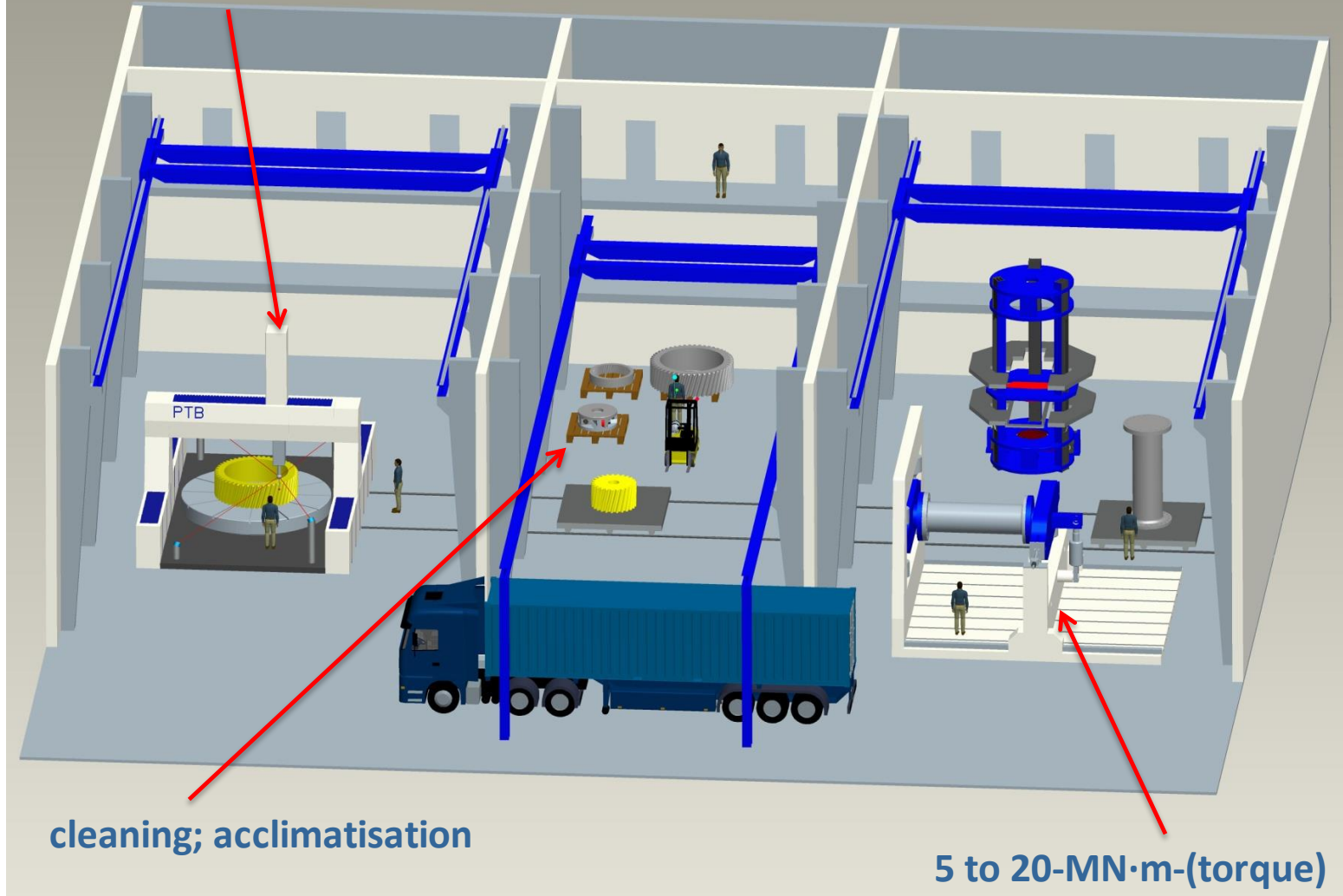
## Calibration of torque

PTB:	1100 kN·m (biggest system worldwide)
Himmelstein (USA):	450 kN·m
SMERI (China):	200 kN·m (biggest system with direct mass)
LNE (Frankreich):	200 kN·m

problem: systems traceable only up to 1100 kN·m



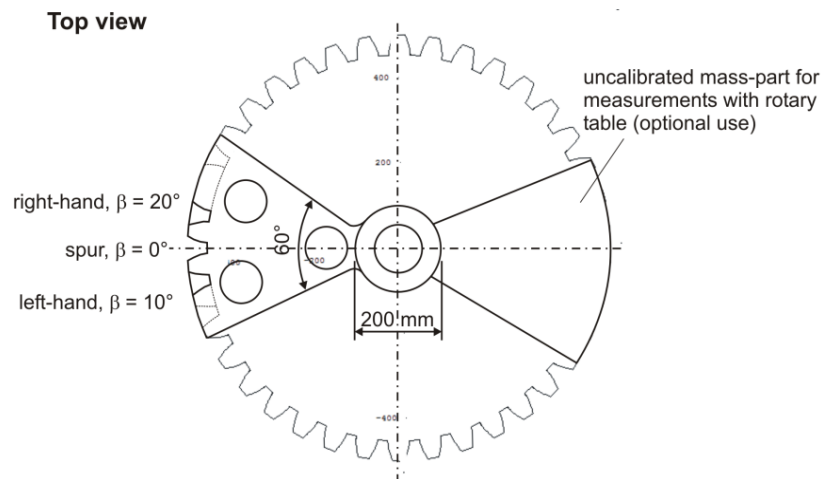
Coordinate Metrology 4m x 5m x 3m



# Calibration for gear measurement today

- measurements in industry
- mover: CMM
- environment: measuring room
- workpiece: calibrated involute gear artefact (reference, validation)

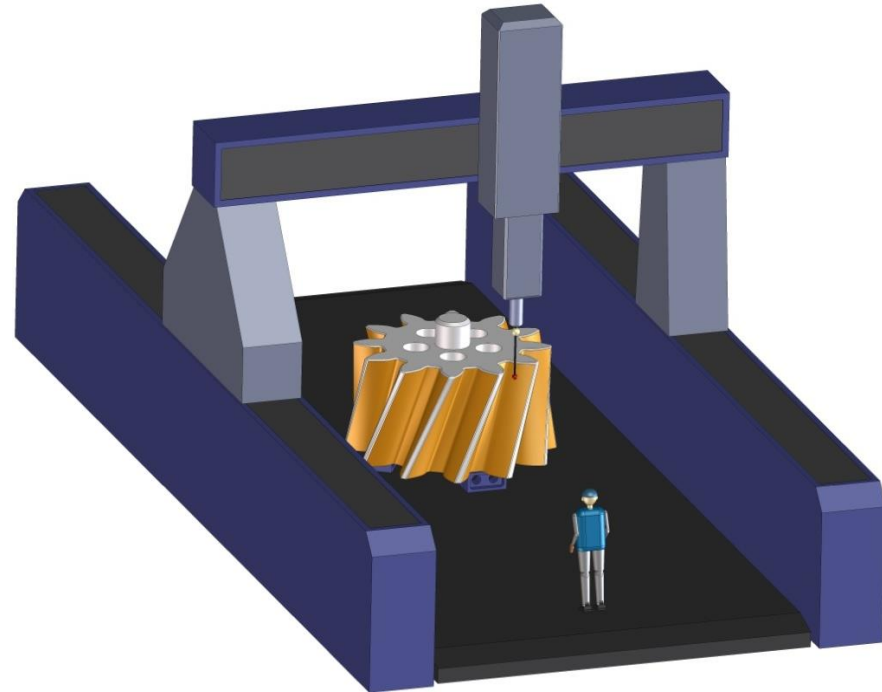
Parameter	Value
Number of teeth $z$	38
Normal module $m_n$	20 mm
Pressure angle $\alpha_n$	20°
Face width $b$	400 mm
Helix angle	0°/spur; 10°/R; 20°/L
Outside diameter $d_a$	1000 mm
Weight	450 kg (700 kg)
Reference bands diameter (form deviation)	200 mm (1 $\mu$ m)



# Concept for precise coordinate measurement of big work pieces 1/4

## 1<sup>st</sup> step – real measurement

- measure workpiece
  - use CMM and application software
- register spatial locations
  - in machine coordinates (x, y, z)
- export of all probing points
  - from the application program



Cartesian CMM (not Abbe error free)

# Concept for precise coordinate measurement of big work pieces 2/4

## 2<sup>nd</sup> step – 3D-Abbe measurement

- remove workpiece
- exchange stylus by triple reflector approximately at same centres

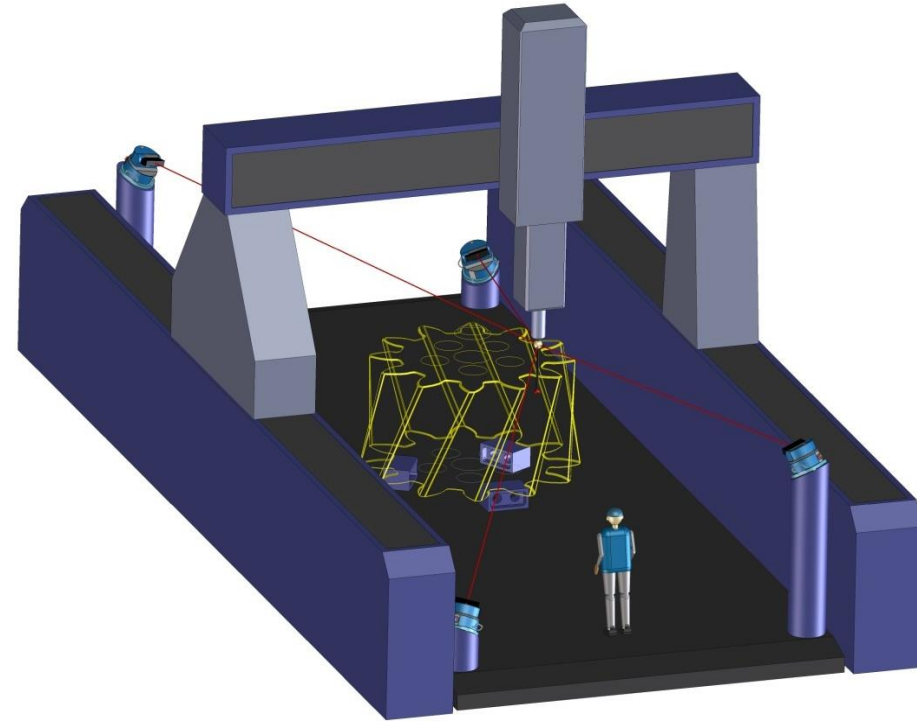


Cat-Eye  
working range 120°



n=2-ball  
working range 160°

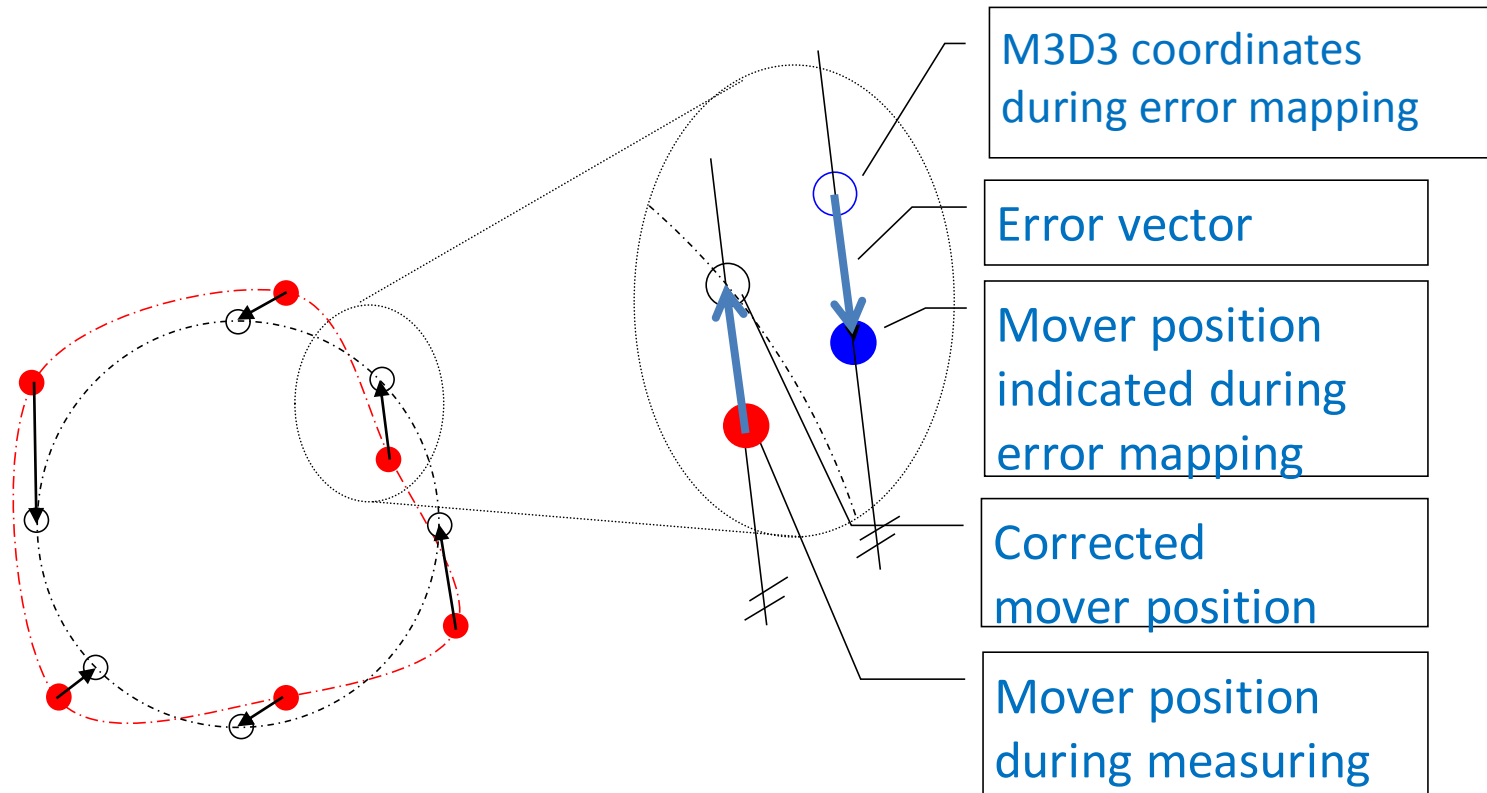
- align at least 4 tracking interferometers
- move to all measurement points measured in step 1
- synchronised read out of all tracking interferometer



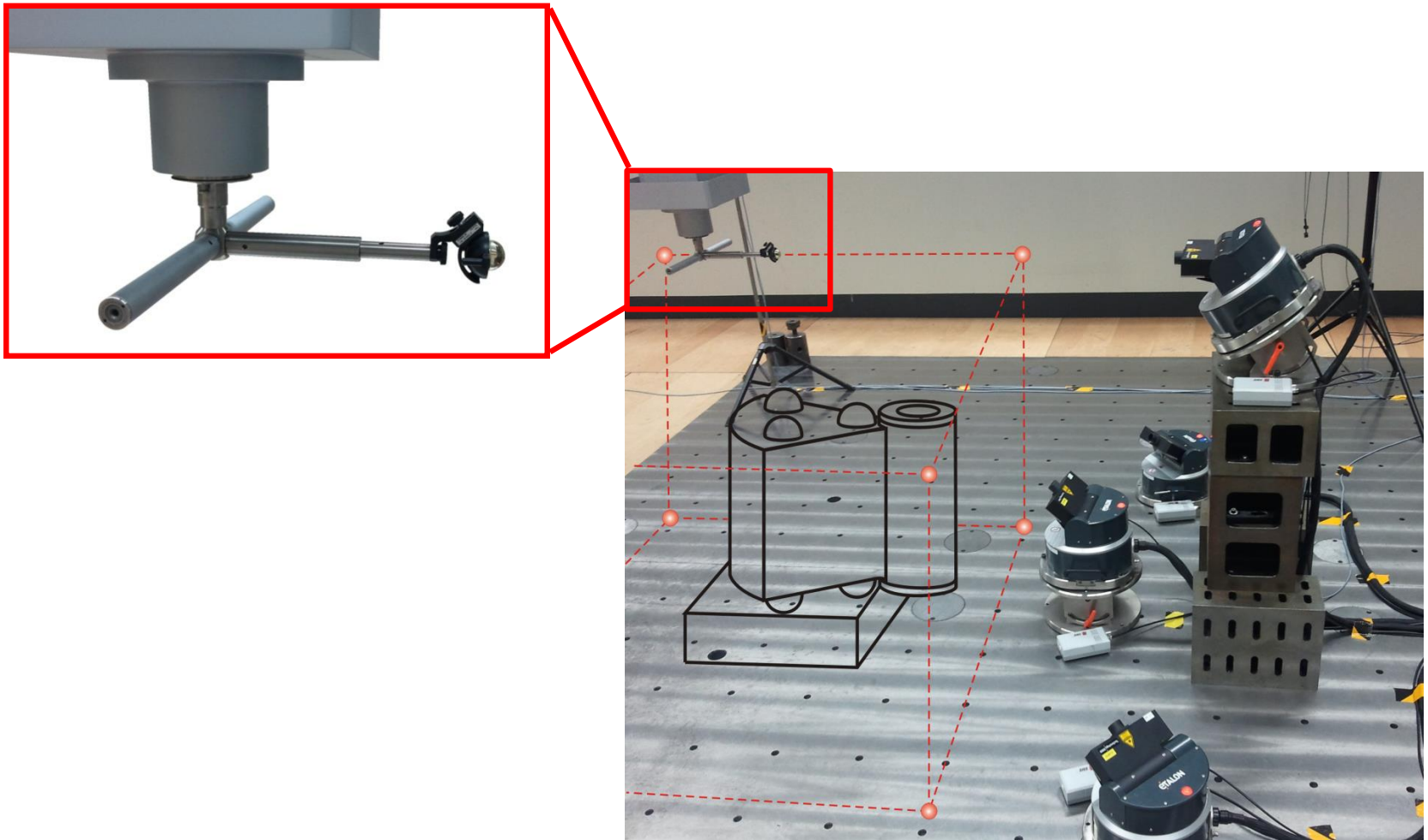
3D Abbe error free  
measurement for  
measurements  
on Cartesian CMMs

# Concept for precise coordinate measurement of big work pieces 3/4

3<sup>rd</sup> step – evaluate the local error vector and correct mover points

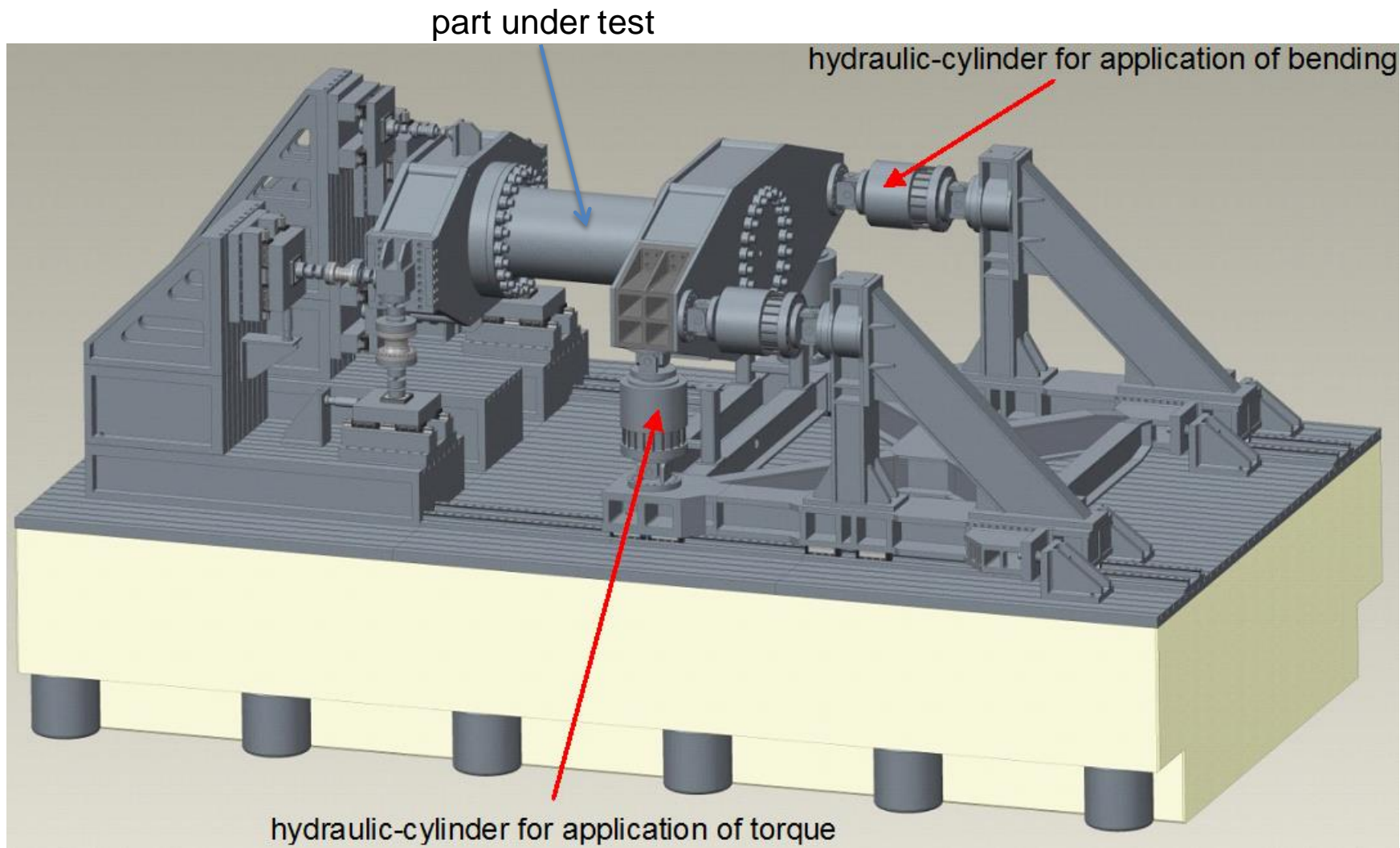


# Concept for precise coordinate measurement of big work pieces 4/4

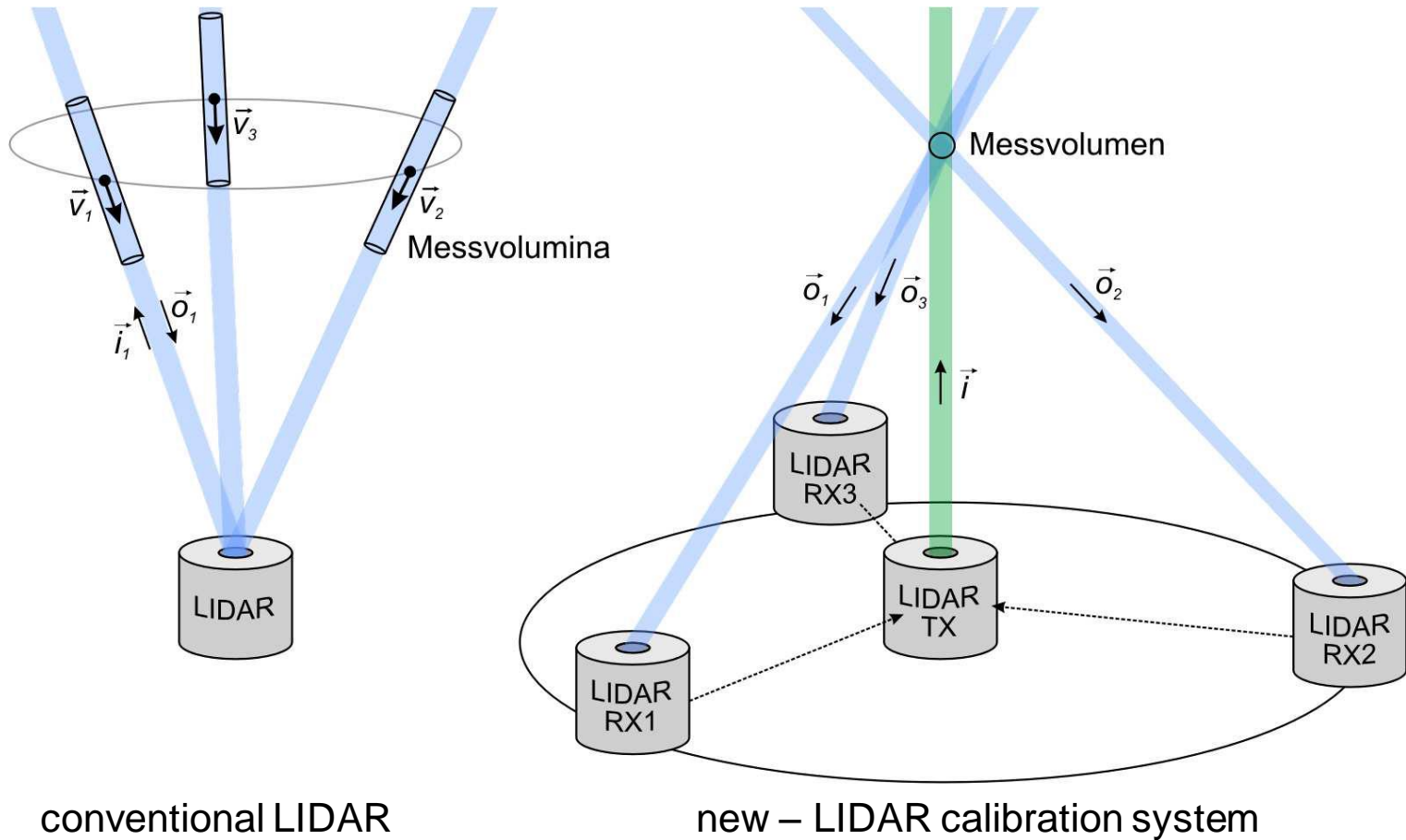




# Calibration of torque 5 MNm to 20 MNm



# Third part of CC-Wind: Wind-Lidar



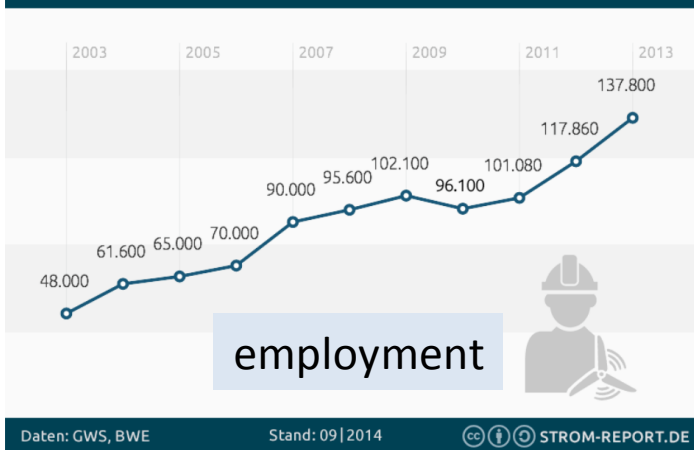
to be calibrated

Measurement height: 10m – 200m  
measuring mast free

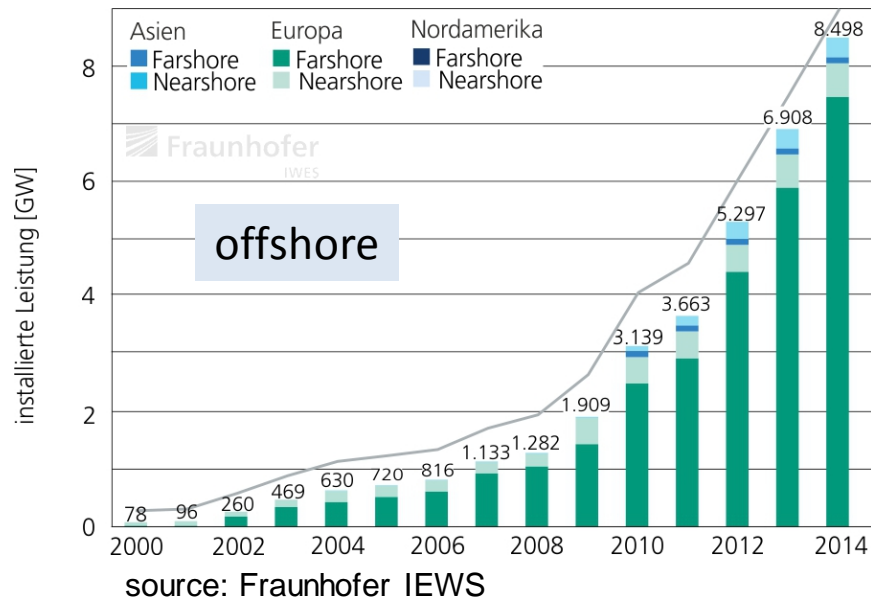
MU: 0,1 m/s; spatial resolution:  $10^{-9} \text{ m}^3$

# Clues for further development and needs

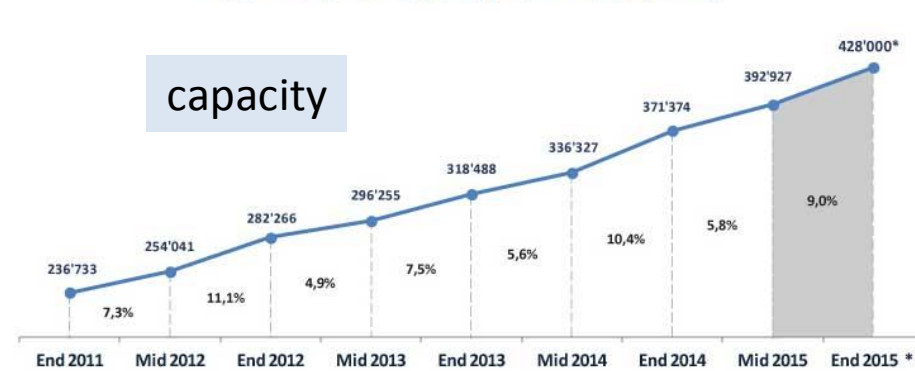
Bruttbeschäftigung Windenergie in Deutschland 2003 - 2013



<http://strom-report.de/>



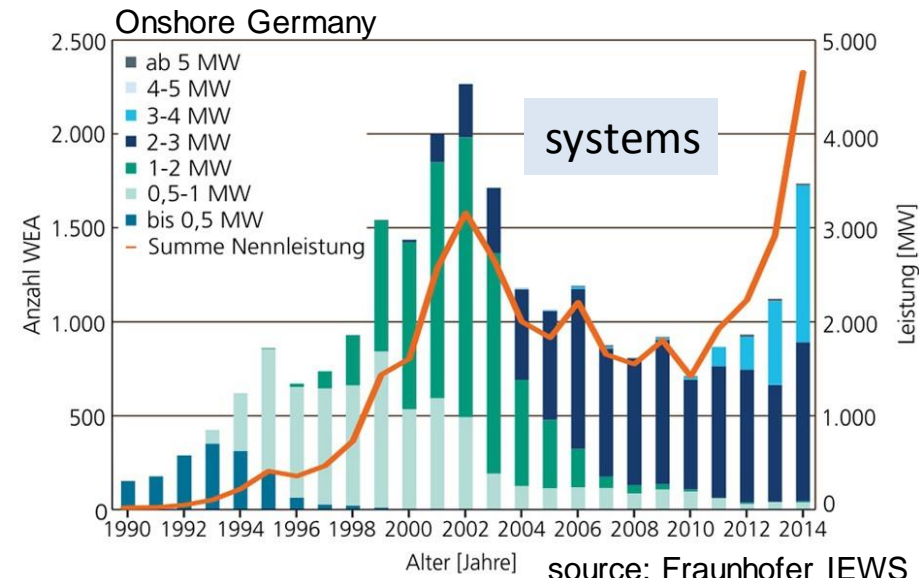
Total Installed Capacity 2011-2015 [MW]



\* Estimated

Total installed capacity: Includes all installed wind capacity, connected and not-connected to the grid.

© WWEA - 2015



# Thank you for your kind attention



## **Physikalisch-Technische Bundesanstalt Braunschweig and Berlin**

Bundesallee 100

38116 Braunschweig

Thomas Wiedenhöfer (Wiedenhofer)

Telefon: +49 (0)531 592-1189

E-Mail: [thomas.wiedenhofer@ptb.de](mailto:thomas.wiedenhofer@ptb.de)

[www.ptb.de](http://www.ptb.de)